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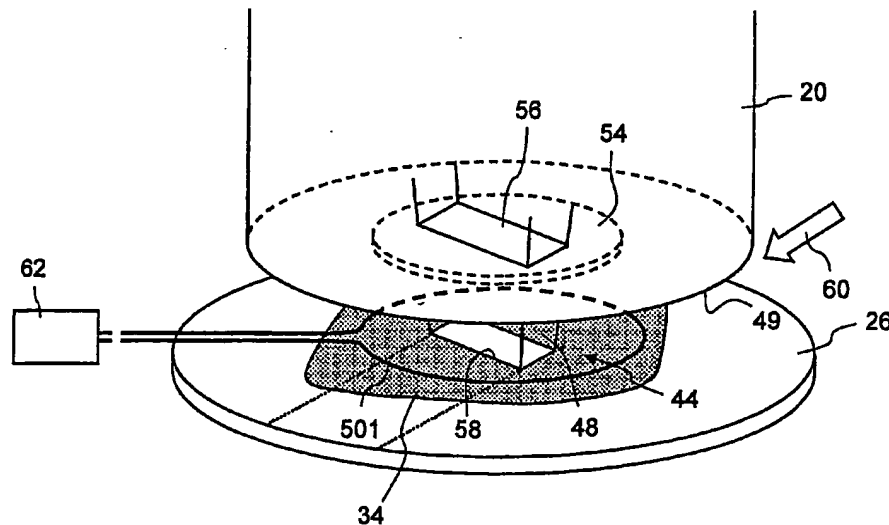
(57) Abstract: A microlithographic projection exposure apparatus includes a projection lens (20) that is configured for immersion operation. For this purpose an immersion liquid (34) is introduced into an immersion space (44) that is located between a last lens (L5; 54) of the projection lens (20) on the image side and a photosensitive layer (26) to be exposed. To reduce fluctuations of refractive index resulting from temperature gradients occurring within the immersion liquid (34), the projection exposure apparatus (10) includes heat transfer elements (50; 501; 502; 503; 504) with which zones of the immersion liquid (34) can be heated or cooled in a specified manner.

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MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS AND MEAS-
URING DEVICE FOR A PROJECTION LENS

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BACKGROUND OF THE INVENTION

1.   Field of the Invention

The invention relates to microlithographic projection ex-
posure apparatuses as used for manufacturing highly-
5   integrated electrical circuits and other microstructured
components. In particular, the invention relates to pro-
jection exposure apparatuses configured for immersion op-
eration. The invention further provides measuring devices
for determining the imaging properties of projection
10   lenses.

2.   Description of Related Art

Integrated electrical circuits and other microstructured
components are usually manufactured by applying a plural-
ity of structured layers to a suitable substrate, which
15   may be, for example, a silicon wafer. To structure the
layers, they are first covered with a photoresist that is
sensitive to light of a given wavelength range, e.g.
light in the deep ultraviolet (DUV) spectral range. The
coated wafer is then exposed in a projection exposure ap-
20   paratus. A pattern composed of structures located on a
mask is imaged on the photoresist by means of a projec-

tion lens. Because the imaging scale is generally less
than 1:1, such projection lenses are frequently referred
to as reduction lenses.

After the photoresist has been developed the wafer is
5   subjected to an etching or deposition process whereby the
uppermost layer is structured according to the pattern on
the mask. The remaining photoresist is then removed from
the remaining parts of the layer. This process is re-
peated until all the layers have been applied to the wa-
10   fer.

One of the primary design objectives in the development
of projection exposure apparatuses is to be able to
lithographically define structures of increasingly small
dimensions. Small structures lead to high integration
15   densities, which generally have a favourable effect on
the efficiency of microstructured components manufactured
using such apparatuses.

The size of the definable structures depends, above all,
on the resolution of the projection lens used. Because
20   the resolution of projection lenses improves as the wave-
length of the projection light becomes shorter, one ap-
proach to decrease the resolution is to use projection
light having shorter and shorter wavelengths. The short-
est wavelengths currently used are 193 nm and 157 nm,
25   i.e. in the deep ultraviolet (DUV) spectral range.

Another approach to decrease the resolution is based on the concept of introducing an immersion liquid having a high refractive index into the space located between a last lens of the projection lens on the image side and

5 the photoresist or another photosensitive layer to be exposed. Projection lenses, which are designed for immersion operation and are therefore also referred to as immersion lenses, can attain numerical apertures of greater than 1, e.g. 1.3 or 1.4. However, immersion not only

10 makes possible high numerical apertures and therefore an improved resolution, but also has a favorable effect on depth of focus. The greater the depth of focus, the less high are the demands for precise positioning of the wafer in the image plane of the projection lens.

15 A projection exposure apparatus designed for immersion operation is known from US 4 346 164 A. To accommodate a wafer, this known projection exposure apparatus has an upwardly open container with an upper edge that is located higher than the lower boundary face of the last

20 lens of the projection lens on the image side. Inlet and outlet pipes for an immersion liquid open into the container. These pipes are connected to a pump, a temperature-stabilizing device and a filter for cleaning the immersion liquid. During operation of the projection expo-

25 sure apparatus, the immersion liquid is circulated in a loop. An immersion space located between the lower boundary face of the last lens of the projection lens on the

image side and the semiconductor slice to be exposed re-
mains filled the immersion liquid.

A projection exposure apparatus having an immersion ar-
rangement is also known from WO 99/49504. In this projec-
5   tion exposure apparatus the supply and discharge pipes
for the immersion liquid open directly onto the lower
boundary face of the last lens of the projection lens on
the image side. The use, in particular, of a plurality of
such supply and discharge pipes, which may be arranged,
10 for example, in a ring around the last lens on the image
side, makes it possible to dispense with a surrounding
container. This is because immersion liquid is sucked
away as it runs off laterally and is fed back in such a
way that the immersion space between the last lens on the
15 image side and the photosensitive surface always remains
filled with immersion liquid.

A difficulty with the immersion operation of projection
exposure apparatuses is to keep the optical characteris-
tics of the immersion liquid constant, at least where the
20 liquid is exposed to the projection light. Special atten-
tion must be paid to the absorption and the refractive
index of the immersion liquid. Local fluctuations in the
absorption, as can be produced, for example, by impuri-
ties, lead to undesired intensity fluctuations in the im-
25 age plane. As a result, line width fluctuations may occur
even if the imaging is otherwise free of substantial ab-
errations.

Local fluctuations in the refractive index of the immer-
sion liquid have an especially detrimental effect, since
such fluctuations directly impair the imaging character-
istics of the projection exposure apparatus. If the re-
5   fractive index of the immersion liquid is inhomogeneous
within the volume of the immersion liquid exposed to the
projection light, this causes distortions of the wave
fronts passing through the immersion space. For example,
points in the object plane of the projection lens may no
10 longer be imaged sharply on the image plane.

The refractive index of liquids is dependent on their
density. Because liquids are virtually incompressible,
their density is practically independent of static pres-
sure and depends almost exclusively on the temperature of
15 the liquids. For this reason, the immersion liquid inside
the immersion space that is exposed to the projection
light can have a homogeneous refractive index only if the
temperature of the immersion liquid is constant therein.
Moreover, temperature fluctuations within the immersion
20 liquid not only cause fluctuations of refractive index,
but can also cause adjacent optical elements, in particu-
lar the last optical element of the projection lens on
the image side, to be heated unevenly and therefore to be
deformed in a manner that can hardly be corrected.

25 The causes that give rise to inhomogeneities of the tem-
perature in the immersion space are diverse. A major
cause for heating the immersion liquid is the absorption

of projection light by the immersion liquid. Even if only
a small percentage of the projection light is absorbed by
the immersion liquid, this causes a comparatively high
heat input because of the short-wave and therefore en-
5   ergy-rich projection light. An effect which leads to
cooling of the immersion liquid is the evaporation of im-
mersion liquid at the boundary surface to a surrounding
gas. In addition, the temperature of the immersion liquid
is influenced by heat transitions from and to surrounding
10   solid bodies. These bodies may be, for example, a heated
last lens of the projection lens, its housing or the wa-
fer to be exposed.

To homogenize the temperature, it has been proposed hith-
erto to circulate the immersion liquid in a circuit and
15   to establish a desired reference temperature by means of
a temperature-stabilizing device. However, the homogeni-
zation of temperature distribution that can be achieved
in this way is frequently not sufficient. Relatively high
flow velocities, which may lead to disturbing vibrations,
20   are usually required. In addition, high flow velocities
promote the formation of gas bubbles which can also ad-
versely affect the imaging properties.

Moreover, similar difficulties also arise in measuring
devices with which the imaging characteristics of such
25   projection lenses can be determined. If immersion lenses
having numerical apertures of greater than 1 are to be
measured, it is also necessary to introduce an immersion

liquid into an immersion space located between the last
optical element of the projection lens on the image side
and a test optics component of the measuring device. Be-
cause of the extremely high demands on the measuring ac-
5 curacy of such devices, inhomogeneities of refractive in-
dex within the immersion liquid cannot be tolerated.

SUMMARY OF THE INVENTION

It is therefore the object of the invention to improve a
projection exposure apparatus, and a measuring device for
10 the optical measurement of projection lenses, such that
imaging defects resulting from inhomogeneities of the re-
fractive index within the immersion liquid are reduced.

This object is achieved in that the projection exposure
apparatus and the measuring device include a heat trans-
15 fer element with which the temperature can be changed in
a specified manner in a zone of the immersion space.

The invention is based on the discovery that a desired
temperature distribution within the immersion space can
be attained if heat is supplied to or extracted from the
20 immersion liquid in a spatially specified manner. It is
known in general where and to what degree heat is trans-
ferred into the immersion liquid or dissipated therefrom
to surrounding media. If these causes of temperature
fluctuations are carefully analyzed, it is possible to
25 determine the temperature distribution which the immer-

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sion liquid inside the volume of the immersion space
through which projection light passes can be expected to
have, if no additional measures are taken to change the
temperature distribution. On the basis of the anticipated
5   temperature distribution it can then be determined at
which locations heat must be supplied or extracted so
that the desired temperature distribution is established.
In general, the aim is to achieve a homogenous tempera-
ture distribution. However, consideration may also be
10   given to establishing a temperature distribution which,
although inhomogeneous, has a certain symmetry. For exam-
ple, with a rotationally symmetrical temperature distri-
bution the immersion liquid would not be free from re-
fractive power but could have the effect of an index
15   lens.

Because of the local heating or cooling of the immersion
liquid according to the invention, continuous circulation
of the immersion liquid in a circuit including a tempera-
ture-stabilizing arrangement may be dispensed with, if
20   desired. In this way vibrations produced by the circula-
tion of the immersion liquid are avoided, as is particu-
larly advantageous in the case of measuring devices. If
the immersion liquid is not to be completely exchanged at
regular intervals, consideration may be given to a dis-
25   continuous circulation. This means that the immersion
liquid is circulated by means of a pump, while being
cleaned and optionally additionally cooled or heated,
only during exposure or measuring pauses. With regard to

the avoidance of vibration, such discontinuous circula-
tion may be advantageously used even independently of the
heat transfer element according to the invention.

If a homogeneous temperature distribution is desired,
5   this will generally result in the heat transfer elements
being arranged with a symmetry corresponding to that of
the immersion space. Rotationally symmetrical arrange-
ments of the heat transfer elements are therefore pre-
ferred. In the case of slit-shaped light fields, as are
10 projected onto the wafer with projection exposure appara-
tuses designed for scanning operation, for example, the
heat transfer elements may also be arranged differently,
e.g. corresponding to the geometry of the light fields.

As a heat transfer element, any body that is suited to
15 exchanging heat with the immersion liquid by way of ther-
mal conduction or radiation is in principle possible. De-
pending on whether heat passes from the heat transfer
element to the immersion liquid or vice versa, local
heating or cooling of the immersion liquid occurs.

20 The heat transfer element may be arranged, for example,
inside the immersion space, so that it comes into contact
with the immersion liquid during immersion operation. In
the simplest case, the heat transfer element is then an
electrically heatable heating wire which is preferably
25 covered with an electrically insulating and chemically
protective layer. Such a heating wire has the advantage

that it can be given practically any desired shape. As a
result, heat can be supplied to the immersion liquid at
any desired location inside the immersion space but out-
side the volume through which the projection light
5   passes.

Because the projection light generally produces a rela-
tively large heat input due to absorption, the heating
wire may be arranged, for example, in an annular configu-
ration around the volume through which projection light
10 passes. The calorific output is then preferably selected
such that the temperature gradient in the volume through
which projection light passes is minimized.

A still more precisely specified heat input is possible
if, as an additional parameter, the wire diameter is var-
15 ied. In this way the calorific output can also be varied
along the longitudinal extension of the heating wire.

Instead of an electrically heatable heating wire, a con-
duit through which a fluid heating medium flows, e.g.
heated or cooled water, may also be used as a heat trans-
20 fer element. In this case, too, the heating or cooling
power can be varied in the longitudinal direction of the
conduit by varying the flow cross-section.

If the immersion liquid is prevented from escaping by a
wall laterally bordering the immersion space, the heat
25 transfer element may also be arranged in this wall. Also

in this case a configuration of the heat transfer element
as an electrically heatable heating wire or a conduit
through which a heating medium can flow is contemplated.
In this way the wall itself forms, so to speak, a single
5   large heat transfer element.

For locally cooling the immersion liquid a Peltier ele-
ment may be used as heat transfer element.

In an particularly advantageous embodiment, the heat
transfer element is spaced from the immersion space in
10   such a way that heat can be exchanged between the heat
transfer element and the zone by thermal radiation, e.g.
by infrared or microwave radiation. In this case the heat
transfer element may be, for example, in the form of a
preferably electrically heatable or coolable planar ra-
15   diator. Heat transfer by radiation has the advantage over
heat transfer by conduction that no direct physical con-
tact between the heat transfer element and the immersion
liquid is required. The heat transfer element can there-
fore be arranged at a greater distance from the immersion
20   liquid. In this embodiment, possible difficulties arising
through the installation of heat transfer elements in the
narrow immersion space or adjacently thereto are avoided.

In order to direct the thermal radiation more selectively
from a heat transfer element to the immersion liquid in
25   this embodiment, one or more optical elements, for exam-
ple mirrors or lenses, which change the direction of the

thermal radiation may be arranged between the heat trans-
fer element and the immersion space. By using optical
elements having positive refractive power, thermal radia-
tion can be focused in a specified manner into the narrow
5 gap between the projection lens and the wafer and onto
the desired zone of the immersion space.

In principle, it is even possible to arrange one or more
of these optical elements inside the projection lens in
order to direct thermal radiation onto the desired zone
10 of the immersion space. It is also possible in this case
to couple thermal radiation into the beam path of the
projection lens in such a way that said thermal radiation
exits the last lens of the projection lens on the image
side separately from the projection light. With a suita-
15 bly selected beam path, the thermal radiation heats ex-
clusively a partial volume of the immersion liquid which
surrounds the volume through which the projection light
passes, thus reducing the temperature gradient at the
edge of this volume. It must then be ensured only that
20 the thermal radiation has a wavelength to which the
photoresist is insensitive.

To measure the temperature in the immersion liquid in a
contactless manner, the temperature of a heat transfer
element may be determined, wherein the temperature of the
25 heat transfer element can be changed only by exchange of
thermal radiation with the immersion liquid. Under these
conditions, given a known calorific output and tempera-

ture of the heat transfer element, conclusions may be
drawn regarding the temperature of the immersion liquid.
To measure the temperature of such a heat transfer ele-
ment, it may be connected to a thermal sensor. The latter
5 may in turn be in signalling connection to a control de-
vice which regulates the heating or cooling output of the
heat transfer element.

In the case of projection exposure apparatuses which are
not operated in scanning mode but step-by-step, a wafer
10 stage, on which the carrier of the photosensitive layer
can be fixed, may be considered as a location for mount-
ing a heat transfer element according to the invention.
In this way the carrier may be locally heated or cooled
from below. Thus, the temperature of the immersion liquid
15 located above the carrier can also be changed by thermal
conduction. This configuration also provides a possibil-
ity of cooling the volume of immersion liquid exposed to
the projection light. Other cooling measures are in gen-
eral difficult because this volume is not easily accessi-
20 ble either from above or from the side.

According to another aspect of the invention, the above-
mentioned object is achieved in that an evaporation bar-
rier, which at least partially surrounds the immersion
space, is arranged on an underside of the projection lens
25 facing towards the photosensitive layer.

According to this second aspect of the invention, one of
the major causes leading to the formation of temperature
gradients in the immersion space is largely eliminated.
The evaporation barrier prevents immersion liquid from
5 evaporating to a large extent into a surrounding gas vol-
ume.

For this purpose the evaporation barrier may include, for
example, one or more at least approximately concentric
rings having, for example, a circular or polygonal shape,
10 which are arranged at a distance from one another. In
this way the boundary surface to the surrounding gas is
reduced so that less immersion liquid can evaporate.

According to a further aspect of the invention the evapo-
ration of immersion liquid is wholly or at least par-
15 tially prevented in that an outer chamber surrounding the
immersion space and in fluid connection therewith with
can be enriched with a vapor phase of the immersion liq-
uid.

Through the enrichment of this outer chamber with a vapor
20 phase of the immersion liquid the vapor pressure in the
outer chamber can be increased until hardly any immersion
liquid can pass from the liquid phase to the vapor phase.
In the ideal case, the pressure of the vapor phase in the
outer chamber is adjusted such that it at least approxi-
25 mately equals the saturation vapor pressure of the vapor
phase at the temperature prevailing in the outer chamber.

In this case, exactly the same amount of immersion liquid
evaporates at the boundary surface between the immersion
liquid and the vapor phase as simultaneously condenses
from the vapor phase. As a result of this equilibrium,
5 the temperature of the immersion liquid in proximity to
the boundary surface remains unchanged.

To producing a vapor phase of the immersion liquid in the
outer chamber, a supply device for introducing a vapor
phase of the immersion liquid into the outer chamber may
10 be provided.

The embodiments explained below can be advantageously
used with all the above aspects of the invention and even
independently thereof.

The feed pipes for the immersion liquid are normally
15 firmly connected, e.g. clamped or press-fitted, to a wall
delimiting the immersion space laterally and downwardly.
This may transfer vibrations from outside to the immer-
sion liquid. To avoid such vibrations, in particular with
measuring devices, an aperture for a pipe leading into
20 the immersion space may be provided in such a wall. The
dimensions of the aperture are sufficiently larger than
the external dimensions of the pipe so that immersion
liquid can enter a gap remaining between the pipe and the
wall, but cannot flow out of said gap as a result of ad-
25 hesion forces. The adhesion forces therefore effect a
seal of the wall in the region of the aperture although

the pipe is longitudinally displaceable therein. A trans-
mission of vibrations from the pipe to the wall and from
there to the immersion liquid is considerably reduced by
the liquid-filled gap.

5   In addition, it is advantageous if a detector for detect-
ing immersion liquid is provided. In particular with pro-
jection exposure apparatuses or measuring devices in
which the immersion liquid is not delimited laterally by
a ring or a container, it is frequently necessary to as-
10   certain whether immersion liquid is still present inside
the region provided therefore or has left this region,
e.g. as a result of inertial forces.

It may be possible to determine, with the help of the de-
tector, whether immersion liquid leaves a predefined
15   closed surface. This closed surface is preferably a sur-
face on the photosensitive layer immediately below the
projection lens.

Such a detector may be realized, for example, in that two
substantially parallel conductors, preferably placed
20   around the closed surface in the manner of the loop, form
a capacitor. If immersion liquid enters the space between
the conductors, this causes an increase in the dielectric
constant, whereby the capacitance of the capacitor is in-
creased. This increase in capacitance can be detected in
25   a simple manner with a suitable measuring circuit, known
per se, for measuring capacitance.

The embodiments of the invention explained above have
been explained predominantly with reference to a projec-
tion exposure apparatus. However, they can be used
equally advantageously with measuring devices for deter-
5 mining imaging characteristics, since a measuring assem-
bly for measuring a projection lens differs only slightly
from a projection exposure apparatus. For example, meas-
uring devices also include a type of illumination system
which generates measuring light and couples it into the
10 projection lens. If no photosensitive test layer is ex-
posed during measurement, the immersion space is delim-
ited downwardly by a test optics component. With a
Twyman-Green or Fizeau interferometer, for example, this
test optics component may be a mirror; with a Moiré or
15 Shearing interferometer it may be a diffraction grating,
and with a Hartmann-Shack sensor it may be a grid-of-
points mask.

If an immersion liquid is introduced into the gap between
the last optical element of the projection lens on the
20 image side and such a test optics component, temperature
stabilization of this immersion liquid is also required.
Because the test optics component – unlike the wafer in a
projection exposure apparatus designed for scanning op-
eration – generally does not move within the image plane,
25 the immersion liquid in the immersion space is not mixed
as a result of such movements, so that still higher tem-
perature gradients can develop. On the other hand, some
of the above-mentioned measures are especially suited to

such measuring devices, since design difficulties arising
as a result of scanning motion do not occur in their
case.

Such a stationary test optics component delimiting the
5   immersion space downwardly enables heat to be dissipated
in a specified manner via the test optics component. If,
for example, the test optics component includes a zone
which is at least partially transparent to light and if
this zone is at least partially surrounded by another
10 zone, this other zone may be made of a material which has
higher thermal conductivity than the material of which
the light-transparent zone consists. An example is a
glass/metal material combination. The metal surrounding
the glass zone ensures efficient heat dissipation for the
15 immersion liquid located above same.

BRIEF DESCRIPTION OF THE DRAWINGS

Various features and advantages of the present invention
may be more readily understood with reference to the fol-
lowing detailed description taken in conjunction with the
20 accompanying drawing in which:

FIG. 1   shows a meridional section through a projec-
           tion exposure apparatus according to the in-
           vention in a greatly simplified representation
           which is not to scale;

FIG. 2   shows an enlarged portion of the projection
exposure apparatus illustrated in FIG. 1, in
which a heat transfer element in the form of a
heatable ring recessed in a housing of the
projection lens on the image side can be seen;

FIG. 3   is a perspective representation of an immer-
sion space according to another embodiment of
the invention in which the heat transfer ele-
ment is a heating wire arranged inside the im-
mersion space;

FIG. 4   shows an axial section through the immersion
space illustrated in FIG. 3;

FIG. 5   is a representation corresponding to FIG. 3
according to a further embodiment of the in-
vention in which the heat transfer element is
integrated in a wall laterally delimiting the
immersion space;

FIG. 6   is a representation corresponding to FIG. 4
according to a further embodiment of the in-
vention in which the heat transfer elements
are thermal radiators;

FIG. 7   is a representation corresponding to FIG. 4
according to yet another embodiment of the in-

vention in which heat transfer elements are
recessed in a wafer stage for fixing a wafer;

FIG. 8   is a representation corresponding to FIG. 4
          according to another aspect of the invention
          in which an evaporation barrier surrounds the
          immersion space laterally to reduce evapora-
          tion;

FIG. 9   shows a partial meridional section through a
          projection exposure apparatus according to a
          further aspect of the invention in which a
          saturated vapor phase of the immersion liquid
          is located above the immersion liquid to re-
          duce evaporation;

FIG. 10   shows a portion of the projection exposure ap-
          paratus illustrated in FIG. 9 in which a
          floating fixing of an inlet pipe is shown;

FIG. 11   is a representation based on FIG. 9 of a pro-
          jection exposure apparatus according to yet a
          further aspect of the invention in which the
          immersion liquid is circulated through the in-
          fluence of gravity;

FIG. 12   is a representation corresponding to FIG. 3 of
          a further embodiment of the invention in which

a detector for detecting laterally escaping
immersion liquid is provided;

FIG. 13   shows an axial section through the immersion
space illustrated in FIG. 12;

5 FIG. 14   shows an axial section through an immersion
space of a point diffraction interferometer
according to a first embodiment, and

FIG. 15   shows an axial section corresponding to FIG.
14 according to a second embodiment of a point
10   diffraction interferometer according to the
invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows a meridional section through a microlitho-
graphic projection exposure apparatus designated as a
15 whole by 10 in a greatly simplified representation. The
projection exposure apparatus 10 includes an illumination
system 12 for generating projection light 13, which com-
prises a light source 14, illumination optics indicated
at 16 and an aperture 18. In the embodiment illustrated
20 the projection light 13 has a wavelength λ of 193 nm. The
projection exposure apparatus 10 also includes a projec-
tion lens 20 containing a multiplicity of lenses, only
some of which are indicated as examples in FIG. 1 for
reasons of clarity, and which are denoted by L1 to L5.

The projection lens 20 serves to image a mask 24 arranged
in an object plane 22 of the projection lens 20 on a re-
duced scale on a photosensitive layer 26. The layer 26,
which may consist, for example, of a photoresist, is ar-
5   ranged in an image plane 28 of the projection lens 20 and
is applied to a carrier 30.

The carrier 30 is fixed to the bottom of a basin-like,
upwardly open container 32 which is movable parallel to
the image plane 28 (in a manner not illustrated in de-
10 tail) by means of a traversing device. The container 32
is filled with an immersion liquid 34 to a level at which
the last lens L5 of the projection lens 20 on the image
side is immersed in the immersion liquid 34 during opera-
tion of the projection exposure apparatus 10. Instead of
15 a lens, the last optical element of the projection lens
20 on the image side may be, for example, a plane-
parallel terminal plate. The refractive index of the im-
mersion liquid 34 approximately coincides with the re-
fractive index of the photosensitive layer 26. In the
20 case of projection light having a wavelength of 193 nm or
248 nm, high-purity deionized water, for example, is pos-
sible as the immersion liquid 34. With shorter wave-
lengths, such as 157 nm, perfluoropolyether (PEPE), for
example, which is commercially available under trade
25 names including Demnum® and Fomblin®, is suitable.

The container 32 is connected via an inlet pipe 36 and an
outlet pipe 38 to a conditioning unit 40 in which ele-

ments including a circulation pump and a filter for
cleaning the immersion liquid 34 are contained. The con-
ditioning unit 40, the inlet pipe 36, the outlet pipe 38
and the container 32 together form an immersion device
5 designated 42 in which the immersion liquid 34 circulates
while being cleaned and maintained at a constant tempera-
ture. The absolute temperature of the immersion liquid 34
should be set as accurately as possible since imaging by
the projection lens 20 can be impaired by focusing errors
10 and image shell defects in the case of deviations from
the reference temperature. Such imaging defects may in
turn lead to a reduction in size of the process window
available for an exposure.

FIG. 2 shows an enlarged portion of the projection expo-
15 sure apparatus shown in FIG. 1 in which further details
can be seen. In FIG. 2 a gap, referred to hereinafter as
the immersion space, which remains between the last lens
L5 of the projection lens 20 on the image side and the
photosensitive layer 26, is designated 44. For reasons of
20 clarity the height h of the immersion space 44, i.e. the
axial distance between the last optical element of the
projection lens 20 on the image side and the photosensi-
tive layer 26, is greatly exaggerated as represented in
FIG. 2 and in the other Figures; in fact, the height h is
25 of the order of magnitude of only one or a few millime-
ters. In the embodiment illustrated, the immersion space
44 is completely filled with immersion liquid 34, which

flows past the projection lens 20 in a circulation direction indicated by 46.

The projection light indicated by 13 enters the immersion liquid 34 via the last lens L5 on the image side and

5   passes through said immersion liquid 34 in the zone of a volume 48 shaded grey in FIG. 2. The shape of the volume 48 depends on the numerical aperture NA of the projection lens 20 and on the geometry of the light field that is projected by the projection lens 20 onto the photosensi-

10 tive layer 26. Because the immersion liquid 34 has an absorption – although a small one – for the projection light 13 of the given wavelength, a part of the projection light 13 is absorbed within the volume 48. The heat released in this way flows into the zone of the immersion

15 space 44 surrounding the volume 48, since the temperature is lower therein, unless suitable counter-measures are taken.

The heat dissipated outwardly leads to the formation of a temperature gradient also within the volume 48. Because

20 the refractive index of the immersion liquid 34 is temperature-dependent, this temperature gradient within the volume 48 causes a corresponding gradient in the refractive index. Such a gradient causes a refractive power which manifests in imaging defects that, if they exceed a

25 certain degree, cannot be tolerated. This effect occurs especially strongly if the immersion liquid 34 in the immersion space 44 does not move or moves only slowly,

since the heat produced by absorption in the volume 48 is
not, or is only slightly, carried away by convection. For
this reason immersion devices in which the immersion liq-
uid does not circulate, or does not circulate perma-
5   nently, with a high flow velocity are especially affected
by these heat-induced effects.

In addition, the boundary surfaces between the immersion
liquid 34 and a surrounding gas or gas mixture, which may
be e.g. air or an inert gas such as helium or nitrogen,
10 also contribute to the formation of a temperature gradi-
ent. At these boundary surfaces, which are designated 47
in FIGS. 1 and 2, the immersion liquid 34 evaporates
which consumes vaporization heat. In this way the immer-
sion liquid 34 is continuously cooled at the boundary
15 surfaces 49, while the volume 48 is heated by the projec-
tion light 13.

In order to reduce or even completely avoid the imaging
defects accompanying a temperature gradient a heat trans-
fer element is provided. In the embodiment of FIGS. 1 and
20 2, this heat transfer element is realized as a heatable
ring 50 that is recessed in the underside 49 of the pro-
jection lens 20 which is immersed in the immersion liquid
34. The heat emitted from the ring 50 is transmitted by
thermal conduction to the immersion liquid 34, as is in-
25 dicated by arrows 52 in FIG. 2. In this way the zone of
the immersion space 44 surrounding the volume 48 is addi-
tionally heated, counteracting the formation of a tem-

perature gradient. The geometry of the ring 50 may be adapted to the shape of the volume 48. In the case of a rectangular light field, for example, the heat transfer element 50 may also be configured as a rectangular ring.

5 It is, of course, also possible to replace the continuous ring by a plurality of individual heat transfer elements distributed with corresponding geometry on the underside 49 of the projection lens 20.

FIGS. 3 and 4 show a projection exposure apparatus ac-
10 cording to another embodiment in a partial perspective representation and in axial section respectively. In this embodiment the immersion liquid 34 is not located in a container 32 but is retained in the immersion space 44 solely by adhesion forces. In the illustrated embodiment
15 the last optical element of the projection lens 20 on the image side is not a lens but a plane-parallel terminal plate 54. Indicated thereon is a projection light beam denoted by 56 which has an approximately rectangular cross-section. After passing through the terminal plate
20 54 and the immersion liquid 34 located in the immersion space 44 below said terminal plate 54, the projection light beam 56 generates a rectangular light field 58 on the photosensitive layer 26.

In this embodiment the temperature gradient is even
25 steeper than that shown in FIGS. 1 and 2, since the boundary surface 47 between the immersion liquid 34 and a surrounding gas, which boundary surface 47 is compara-

tively cool as a result of evaporation, is here located even closer to the volume 48. In addition, in this embodiment the immersion liquid 34 is not circulated, but remains for a prolonged period in the immersion space 44. In this case, a certain homogenization of the temperature distribution is provided only by mixing of the immersion liquid 34 as a result of a traversing motion 60, indicated by an arrow 60, by which the photosensitive layer 26 is moved past the projection lens 20 during an exposure.

To counteract the formation of a major temperature gradient, in the embodiment illustrated in FIGS. 3 and 4 heat is supplied to the immersion liquid 34 via an annular heating wire 501 that is surrounded by a chemically inert and electrically insulating sheath. The heating wire 501 is connected to a control unit 62 in which a battery for current supply and a control device are integrated. Said control unit 62 has the function of adjusting the calorific output of the heating wire 501 in accordance with a predefined value. Instead of the control device, a temperature control system which includes a temperature sensor for measuring the temperature of the immersion liquid 34 may be provided.

In the embodiment illustrated, the heating wire 501 is in the form of a loop placed around the volume 48 through which the projection light beam 56 passes, so that the immersion liquid 34 located outside the volume 48 can be

uniformly heated by the heating wire 501. The heating
wire 501 may also be arranged more tightly around the
volume 48. Moreover, shapes of the heating wire 501 other
than circular are, of course, envisaged in the context of
5 the present application.

FIG. 5 shows a further embodiment based on the represen-
tation in FIG. 3, indicating how heat transfer elements
may be configured to reduce the temperature gradient. In
this embodiment the immersion space 44 is delimited lat-
10 erally by a ring 62 fixed to the underside 49 of the pro-
jection lens 20. The ring 62 extends downwardly in the
axial direction only so far that the photosensitive layer
26 can be moved past and below the ring 62 during a trav-
ersing movement 60. The ring 62 has the effect that, with
15 relatively fast traversing movements 60, the immersion
liquid 34 does not escape from the immersion space 44. In
addition, the boundary surface 47 to the surrounding gas
or gas mixture is considerably reduced, since the immer-
sion liquid 34 can now evaporate only via a narrow gap of
20 height d remaining below the ring 62.

To homogenize the temperature distribution, the ring 62
is heatable. For this purpose an annular conduit 502, in
which a heating medium, e.g. heated water or hot air, can
circulate is arranged in the lower part of the ring 62.

25 FIG. 6 shows in a partial axial sectional representation
a projection exposure apparatus according to a further

embodiment. In this case the heat transfer elements are realized as planar radiators 503 which are electrically heatable and are distributed around the perimeter of the projection lens 20. The planar radiators 503 have a black

5   surface on their side facing towards the immersion liquid 34 and a mirror surface on the opposite side, so that thermal radiation is directed substantially only at the immersion liquid 34. When heated to temperatures of between approximately 40°C and 80°C, the planar radiators

10 503 emit predominantly thermal radiation having wavelengths in the microwave range, for which water used as the immersion liquid 34 is highly absorptive. Alternatively, however, the heat transfer elements may be other components which emit electromagnetic radiation, e.g.

15 semiconductor diodes or semiconductor lasers. Designated by 65 are thermal sensors with which the temperature of the planar radiators 503 can be measured.

Associated with each planar radiator 503 is a collecting lens 66 which focuses the thermal radiation generated by

20 the planar radiators 503 and directs it at the immersion space 44. The immersion liquid 34 absorbs the thermal radiation predominantly in the area of the boundary surface 47 and is heated locally. In this way heat is generated precisely at the location in the immersion liquid 34

25 where it is lost through evaporation. The larger the absorption coefficient for the wavelength range of the thermal radiation, the more strongly is the heating concentrated on the area of the boundary surfaces 47.

In a practical inversion of the above-described mode of
operation, the arrangement shown in FIG. 6 may also be
used for cooling the immersion liquid 34. In this case it
is necessary only to ensure that the planar radiators 503

5   are cooled, e.g. by means of Peltier elements. In this
case the heat transfer is effected by thermal radiation
from warmer zones of the immersion liquid 34 to the
cooled planar radiators 503.

The arrangement illustrated in FIG. 6 can be further

10   modified so that the planar radiators 503 are arranged
inside the projection lens 20, in such a way that the
thermal radiation emitted passes through the immersion
liquid 34 in the axial direction through suitable exit
windows. Such an arrangement may be considered particu-

15   larly in the case of measuring devices, since then there
is no danger that any short-wave spectral components of
the thermal radiation present will contribute to exposing
the photosensitive layer 26.

FIG. 7 shows a similar portion of a projection exposure

20   apparatus according to another embodiment. Unlike FIGS. 4
and 6, FIG. 7 shows a wafer stage 70 on which the carrier
30 of the photosensitive layer 26 is attached. Incorpo-
rated into the wafer stage 70 are heat transfer elements
which, in the embodiment illustrated, are realized as

25   conduits 504 disposed parallel to one another. When a hot
fluid, e.g. water, flows through the conduits 504, the
zones of the carrier 30 and of the photosensitive layer

26 located above the conduits 504 are heated. From there
the heat passes into the immersion liquid 34 located
above said zones. Because the conduits 504 are offset
laterally with respect to the axial position of the vol-
5   ume 48, the heat transfer is limited substantially to the
zones in the immersion space 44 surrounding the volume
48. In this way the immersion liquid 34 in the immersion
space 44 is heated almost uniformly, which prevents the
formation of major temperature gradients.

10 FIG. 8 shows in an axial section a portion of a projec-
tion exposure apparatus in which no heat transfer ele-
ments are present. In this case homogenization of tem-
perature distribution within the immersion liquid 34 is
achieved in that an evaporation barrier designated as a
15 whole by 72 is fixed to the underside 49 of the projec-
tion lens 20. The evaporation barrier 72 comprises a to-
tal of four concentrically arranged rings 741, 742, 743
and 744, which delimit the immersion space 44 laterally,
i.e. perpendicularly to the optical axis. The rings 741
20 to 744 have, in the axial direction, a width which is
such that the free ends of the rings 741 to 744 are
spaced from the photosensitive layer 26, as is also simi-
larly the case with the embodiment shown in FIG. 5. In
this way the photosensitive layer cannot be damaged by
25 the evaporation barrier 72. Immersion liquid 34 located
inside the immersion space 44 is prevented by adhesion
forces from escaping through the gap 76 remaining between
the ring 741 and the photosensitive layer 26.

Through the staggered arrangement of the rings 741 to 744 it is also prevented that a surrounding gas or gas mixture flows around the gap 76 and thereby promotes evaporation. On the contrary, evaporated immersion liquid 34 remains predominantly in the gaps between the rings 741 to 744, whereby the vapor pressure of the immersion liquid is increased in that location. Because evaporation decreases as the vapor pressure of the surrounding gas increases, an evaporation-inhibiting effect is additionally achieved in this way. This in turn has the result that only a comparatively small temperature gradient can form inside the immersion space 44.

FIG. 9 shows a portion of a projection exposure apparatus 10' similar to that shown in FIG. 1. In the case of the projection exposure apparatus 10', however, the container 32 in which the immersion liquid 34 is located is contained by a chamber 78 sealed all round in a gas-tight manner. The chamber 78 is formed substantially by a hood-like cover 80 which has an opening 82 through which the projection lens 20 passes through the cover 80.

In addition, the projection exposure apparatus 10' includes a supply unit 84 in which elements including a reservoir 86 for immersion liquid 34 and an evaporator 88 are housed. The supply unit 84 has the function of introducing immersion liquid in the vapor phase into the chamber 78 in order to increase the vapor pressure therein. For this purpose immersion liquid withdrawn from the res-

ervoir 86 is evaporated in the evaporator 88 and fed into
the chamber 78 via a conduit 90. The vapor phase of the
immersion liquid can be discharged from the chamber 78 in
a valve-controlled manner via an outlet 92.

5   Because of the increased vapor pressure inside the cham-
    ber 78, only a small amount of immersion liquid 34 evapo-
    rates at the boundary surface 47 between the immersion
    liquid 34 in the liquid phase and in the vapor phase.
    When the saturation vapor pressure is reached in the
10 chamber 78 at the temperature prevailing therein, pre-
    cisely as much immersion liquid 34 evaporates at the
    boundary surface 47 as is condensed inversely from the
    surrounding vapor phase. Therefore, as the saturation va-
    por pressure is reached in the chamber 78, no evaporation
15 heat is consumed that cools off the immersion liquid 34
    located in the container 32. In this way a similar effect
    is obtained as with the embodiment shown in FIG. 8, but
    without the provision of an evaporation barrier 72. The
    projection exposure apparatus 10' therefore makes it pos-
20 sible to conduct immersion liquid 34 through the immer-
    sion space 44 in a closed circulation.

    FIG. 10 shows an enlarged portion A of the projection ex-
    posure apparatus 10' illustrated in FIG. 9. In FIG. 10 a
    wall 94 of the container 32 can be seen, through which
25 the inlet pipe 36 for the immersion liquid 34 passes. For
    this purpose an opening 96 through which the inlet pipe
    36 passes into the interior of the container 32 is pro-

vided in the wall 94. The dimensions of the opening 96
are so selected that a circumferential gap 98 that the
immersion liquid 34 can penetrate remains between the
inlet pipe 36 and the wall 94. On the other hand, the gap

5   98 is so narrow that no immersion liquid 34 can escape
from the container 32 through the gap 98. In this way the
inlet pipe 36, which is held by supports 99, is mounted
so as to "float" in fluid in the wall 94 of the container
32. As a result, vibration of the pipe 36 which may be

10 produced, for example, by flow turbulence in the inlet
pipe or by a pump in the processing unit 40, cannot be
transmitted to the container 32. The above-described
shock-isolated mounting of inlet and outlet pipes can be
of significance, in particular, for measuring devices.

15 FIG. 11 illustrates schematically a portion of another
embodiment of a projection exposure apparatus, denoted as
a whole by 10''. In the projection exposure apparatus
10'', to avoid shocks immersion liquid 34 is not con-
ducted into and through the container 32 by means of a

20 pump, but only by gravity. For this purpose a reservoir
100 for immersion liquid 34 is arranged above the immer-
sion space 44. Immersion liquid 34, controlled by a valve
104, can be conducted from the reservoir 100 into the
container 32. Periodic fluctuations in the flow velocity

25 and vibrations caused thereby, which generally cannot be
completely avoided with the use of pumps, do not occur
with the projection exposure apparatus 102.

In this embodiment the outlet pipe 38 from the container 32 is connected to an intercepting tank 106 in which immersion liquid 34 is collected after passing through a second valve 108. From there the immersion liquid is re-

5 turned by means of a pump 110 to the reservoir 100 via the conditioning unit 40. Because the pump 110 is decoupled from the immersion liquid 34 in the container 32 via the reservoir 100 and the intercepting tank 108, fluctuations in flow velocity generated by the pump 110 are con-

10 fined to the pipe system between the intercepting tank 106 and the reservoir 100.

Another possibility of avoiding shocks produced by pumps consists in circulating the immersion liquid 34 in the container 32 only during projection pauses. The contain-

15 ers 100 and 106 shown in FIG. 11 can then be dispensed with.

FIGS. 12 and 13 show a projection exposure apparatus 10''' according to a further embodiment in a perspective representation and in an axial section respectively. The

20 projection exposure apparatus 10''' includes a detector, denoted as a whole by 120, with which undesired escaping of immersion liquid 34 from the immersion space 44 can be detected. For this purpose the detector 120 has two conductive loops 122, 124 arranged parallel to one another

25 in the axial direction and connected to a measuring circuit 126.

The two conductive loops 122, 124 form a capacitor the capacitance of which depends on factors including the dielectric material located between the conductive loops 122, 124. If, for example, the immersion liquid is deion-

5   ized water and the surrounding gas is air, the difference of dielectric constants is approximately 80. If immersion liquid 34 from the immersion space 44 enters the gap between the conductive loops 122, 124, as is indicated at 128, the dielectric constant of the medium present be-

10 tween the conductive loops 122, 124 is locally increased at that location. The accompanying rise in the capacitance of the capacitor formed by the conductive loops 122, 124 is detected by the measuring circuit 126. If a predefined threshold is exceeded the measuring circuit

15 126 can, for example, generate a signal which indicates that immersion liquid has passed outside the area defined by the conductive loops 122, 124.

The above embodiments have been discussed in relation to projection exposure apparatuses. However, they are trans-

20 ferable, with minor modifications as appropriate, to measuring devices with which the optical imaging characteristics of projection lenses can be determined. Such measuring devices generally include a test optics component which is arranged, in place of the support 30 for

25 the photosensitive layer 26, on the image side of the projection lens 20. This test optics component may be, for example, a mirror, a diffraction grating, a CCD sensor or a photosensitive test layer. Such measuring de-

vices frequently also include separate light sources
which then replace the illumination system of the projec-
tion exposure apparatus.

Some of the above-described embodiments and aspects of
5 the invention can be used especially advantageously with
certain measuring devices. With regard to a Shearing in-
terferometer this is the case, for example, for the vari-
ants shown in FIGS. 3 to 5 and the floating mounting of
pipes shown in FIG. 10; the circulation making use of
10 gravitation illustrated in FIG. 11 is especially advanta-
geous with a Moiré interferometer.

FIG. 14 illustrates schematically a pinhole mask of a
point diffraction interferometer (PDI) in an axial sec-
tion. Such point diffraction interferometers and the pin-
15 hole masks necessitated thereby are known *per se* in the
prior art, so that elucidation of further details thereof
can be omitted. The pinhole mask 140 consists of a glass
body 142 to which a semitransparent layer 144 is applied.
Located at approximately the centre of the pinhole mask
20 140 is a small pinhole opening 146 in the semitransparent
layer 144.

To be able to heat the immersion liquid 34 in the immer-
sion space 44 located above said semitransparent layer
144 in the zones surrounding the volume 48 exposed to the
25 measuring light, conduits 148 through which flows a fluid
heating medium, e.g. heated water, are incorporated in

the glass body 142. In this way the periphery of the glass carrier 142 is heated uniformly, whereby the temperature of the immersion liquid 34 located above same is increased locally.

5 FIG. 15 shows another embodiment of a pinhole mask, denoted by 140', in a representation corresponding to FIG. 14. In this embodiment the pinhole mask 140 consists of a metal carrier 142' at the centre of which a glass insert 150 is incorporated. This glass insert 150, which may
10 have the form, for example, of a truncated cone, is so dimensioned that the measuring light can pass through the glass insert 150 without reaching the surrounding metal of the metal carrier 142'.

Because the volume 48 through which the measuring light
15 passes predominantly borders the metal carrier 142' via the semitransparent layer 144 and only a small part thereof borders the glass insert 150, heat released in the volume 48 by absorption of measuring light is efficiently dissipated via the metal carrier 142'. In this
20 way the high thermal conductivity of the metal carrier 142' contributes to permitting only a small temperature gradient within the immersion space 44.

CLAIMS

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1. Microlithographic projection exposure apparatus,
    comprising:

5   -   an illumination system (12) for generating pro-
             jection light (13),

        -    a projection lens (20) for imaging a mask (24)
             on a photosensitive layer (26), said projection
             lens (20) comprising a plurality of optical
10   elements (L1 to L5; 54), and

        -    an immersion space (44) that

             --   is formed between a last optical element
                  (L5; 54) of the projection lens (20) on
                  the image side and the photosensitive
15   layer (26) and

             --   can be filled with an immersion liquid
                  (34),

    characterized by

    a heat transfer element (50; 501; 502; 503; 504) for
20 selectively varying the temperature in a zone of
    the immersion space (44).

2.   Projection exposure apparatus according to claim 1,
     characterized in that the heat transfer element
     (50; 501) is arranged in the immersion space (44)
     in such a way that it comes into contact with the
     immersion liquid (34) during immersion operation.

3.   Projection exposure apparatus according to claim 2,
     characterized in that the heat transfer element is
     a heating wire (501).

4.   Projection exposure apparatus according to claim 1,
     characterized in that the immersion space (44) is
     laterally delimited by a wall (62) in which the
     heat transfer element (502) is arranged.

5.   Projection exposure apparatus according to claim 1,
     characterized in that the heat transfer element is
     a Peltier element (503).

6.   Projection exposure apparatus according to claim 1,
     characterized in that the heat transfer element
     (503) is arranged at a distance from the immersion
     space (44) so that heat can be exchanged by thermal
     radiation between the heat transfer element (503)
     and the zone.

7.   Projection exposure apparatus according to claim 6,
     characterized by a directive optical element (66)
     that changes the direction of the thermal radiation

and is arranged between the heat transfer element
(503) and the immersion space (44).

8.   Projection exposure apparatus according to claim 7,
characterized in that the directive optical element
(66) has a positive refractive power.

9.   Projection exposure apparatus according to any one
of claims 6 to 8, characterized in that the heat
transfer element is a planar radiator (502) that
can be heated or cooled.

10.   Projection exposure apparatus according to any one
of claims 6 to 9, characterized by a thermal sensor
(65) for measuring the temperature of the heat
transfer element (503).

11.   Projection exposure apparatus according to claim
10, characterized in that the thermal sensor (65)
is connected to a control device which adjusts the
heating or cooling output of the heat transfer ele-
ment.

12.   Projection exposure apparatus according to any one
of the preceding claims, characterized in that the
heat transfer element (504) is arranged in a wafer
stage (70) for positioning a carrier (30) on which
the photosensitive layer (26) is applied.

13. Projection exposure apparatus according to claim
     12, characterized in that the heat transfer element
     (504) has substantially the same symmetry as a
     light field (58) illuminated on the photosensitive
5   layer (26).

14. Projection exposure apparatus according to claim 12
     or 13, characterized in that the heat transfer ele-
     ment includes a plurality of conduits (504) con-
     tained in the wafer stage (70) for conducting a
10   heating or cooling medium through said wafer stage
     (70).

15. Microlithographic projection exposure apparatus,
     comprising:

     −   an illumination system (12) for generating pro-
15   jection light (13),

     −   a projection lens (20) for imaging a mask (24)
          on a photosensitive layer (26), said projection
          lens (20) comprising a plurality of optical
          elements (L1 to L5; 54), and

20   −   an immersion space (44) that

          −−   is formed between a last optical element
               (L5; 54) of the projection lens (20) on

the image side and the photosensitive
layer (26) and

-- can be filled with an immersion liquid
(34),

5   characterized by

an evaporation barrier (72) which

-    at least partially surrounds the immersion
space (44),

-    is arranged on an underside (49) of the projec-
10   tion lens (20) and

-    extends towards the photosensitive layer (26).

16.   Projection exposure apparatus according to claim
15, characterized in that the evaporation barrier
(72) includes a plurality of at least approximately
15   concentric rings (741 to 744) that are arranged at
a distance from one another.

17.   Projection exposure apparatus for microlithography,
comprising:

-    an illumination system (12) for generating pro-
20   jection light (13),

-       a projection lens (20) for imaging a mask (24)
        on a photosensitive layer (26), said projection
        lens (20) comprising a plurality of optical
        elements (L1 to L5; 54), and

5   -   an immersion space (44) that

        --   is formed between a last optical element
                (L5; 54) of the projection lens (20) on
                the image side and the photosensitive
                layer (26) and

10   --   can be filled with an immersion liquid
                (34),

        characterized in that

        an outer chamber (78) surrounding the immersion
        space (44) and in fluid communication therewith is
15   configured to become enriched with a vapor phase of
        the immersion liquid.

18.   Projection exposure apparatus according to claim
        17, characterized by a supply device (84) for feed-
        ing a vapor phase of the immersion liquid into the
20   outer chamber (78).

19.   Projection exposure apparatus according to claim 17
        or 18, characterized in that the pressure of the

vapor phase of the immersion liquid in the outer
chamber (78) is so adjustable that it is at least
approximately equal to the saturation vapor pres-
sure of the vapor phase of the immersion liquid at
the temperature prevailing in the outer chamber
(78).

20. Projection exposure apparatus according to any one
of the preceding claims, characterized in that the
immersion space (44) is delimited by a wall (94) in
which an aperture (96) for a pipe (36) leading into
the immersion space is provided, the dimensions of
the aperture (96) being larger than the external
dimensions of the pipe (36) by an amount such that
immersion liquid (34) can enter a gap (98) remain-
ing between the pipe (36) and the wall (94) but
cannot flow out of said gap (98) because of adhe-
sion forces.

21. Projection exposure apparatus according to any one
of the preceding claims, characterized in that a
container (100) for immersion liquid (34) is ar-
ranged above the immersion space (44) and is in
fluid communication therewith, so that immersion
liquid (34) can flow from the container (100) into
the immersion space (44) solely as a result of
gravity.

22. Projection exposure apparatus according to any one of the preceding claims, characterized by a detector (120) for detecting immersion liquid (34).

23. Projection exposure apparatus according to claim 22, characterized in that the detector (120) is configured such it can determine whether immersion liquid (34) leaves a predefined closed area.

24. Projection exposure apparatus according to claim 23, characterized in that the closed area is arranged on the photosensitive layer (26) below the projection lens (20).

25. Projection exposure apparatus according to claim 23 or 24, characterized in that the detector (120) includes two conductors (122, 124) disposed substantially parallel to one another.

26. Projection exposure apparatus according to claim 25, characterized in that the detector (120) includes a measuring circuit (126) for measuring the capacitance between the conductors (122, 124).

27. Measuring device for determining the imaging characteristics of a projection lens (20) of a microlithographic exposure apparatus, comprising a test optics component (140; 140') that is arranged on the image side of the projection lens (20),

characterized in that

an immersion liquid (34) can be introduced into an immersion space (44) formed between a last optical element (54) of the projection lens (20) on the image side and the test optics component (140; 140'), and

the measuring device includes a heat transfer element (148) for selectively changing the temperature in a zone of the immersion space (44).

28. Measuring device according to claim 27, characterized in that the test optics component (140; 140') includes a zone (150) at least partially transparent to light, and in that the zone (150) transparent to light is at least partially surrounded by another zone (142') consisting of a material that has higher thermal conductivity than the material of which the zone (150) transparent to light consists.

29. Measuring device according to claim 28, characterized in that the test optics component is a pinhole mask (140; 140') of a point diffraction interferometer.

30. Method for producing a projection lens (20) for a microlithographic projection exposure apparatus (10), comprising the following steps:

5
    a)   assembling a projection lens from a plurality of optical elements;

    b)   installing the projection lens in a measuring device which includes a test optics component (140; 140') that is arranged on the image side of the projection lens (20);

10
    c)   introducing an immersion liquid (34) into an immersion space (44) remaining between a last optical element (54) of the projection lens (20) on the image side and the test optics component (140; 140');

15
    d)   selectively varying the temperature of the immersion liquid (34) in a zone of the immersion space (44) by means of a heat transfer element (50; 501; 502; 503; 504);

    e)   determining the imaging characteristics of the projection lens (20);

20
    f)   adjusting the position of at least one optical element of the projection lens (20).

31. Projection lens produced using a method according to claim 30.

32. Method for the microlithographic production of a microstructured component, comprising the following

5   steps:

a)   providing a projection lens (20);

b)   arranging a mask (24) in an object plane (22) of the projection lens (20);

c)   introducing an immersion liquid (34) into an

10   immersion space (44) formed between a last op- tical element (L5; 54) of the projection lens (20) on the image side and a photosensitive layer (26) that is arranged in an image plane (22) of the projection lens (20);

15   d)   selectively varying the temperature of the im- mersion liquid (34) in a zone of the immersion space (44) by means of a heat transfer element (50; 501; 502; 503; 504);

e)   projecting the mask (24) onto the photosensi-

20   tive layer (26).

33. Method according to claim 32, characterized in that the immersion liquid (34) is circulated in the im-

mersion space by means of a pump solely during time
intervals in which no projection according to claim
e) takes place.

34. Microstructured component, characterized in that it
     is produced by a method according to claim 32 or
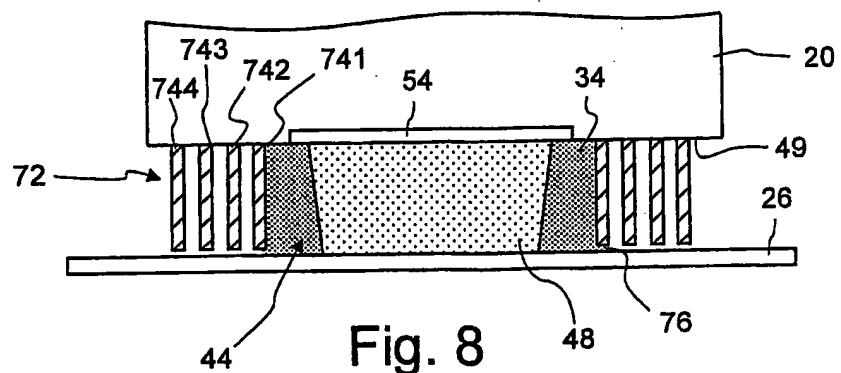   33.
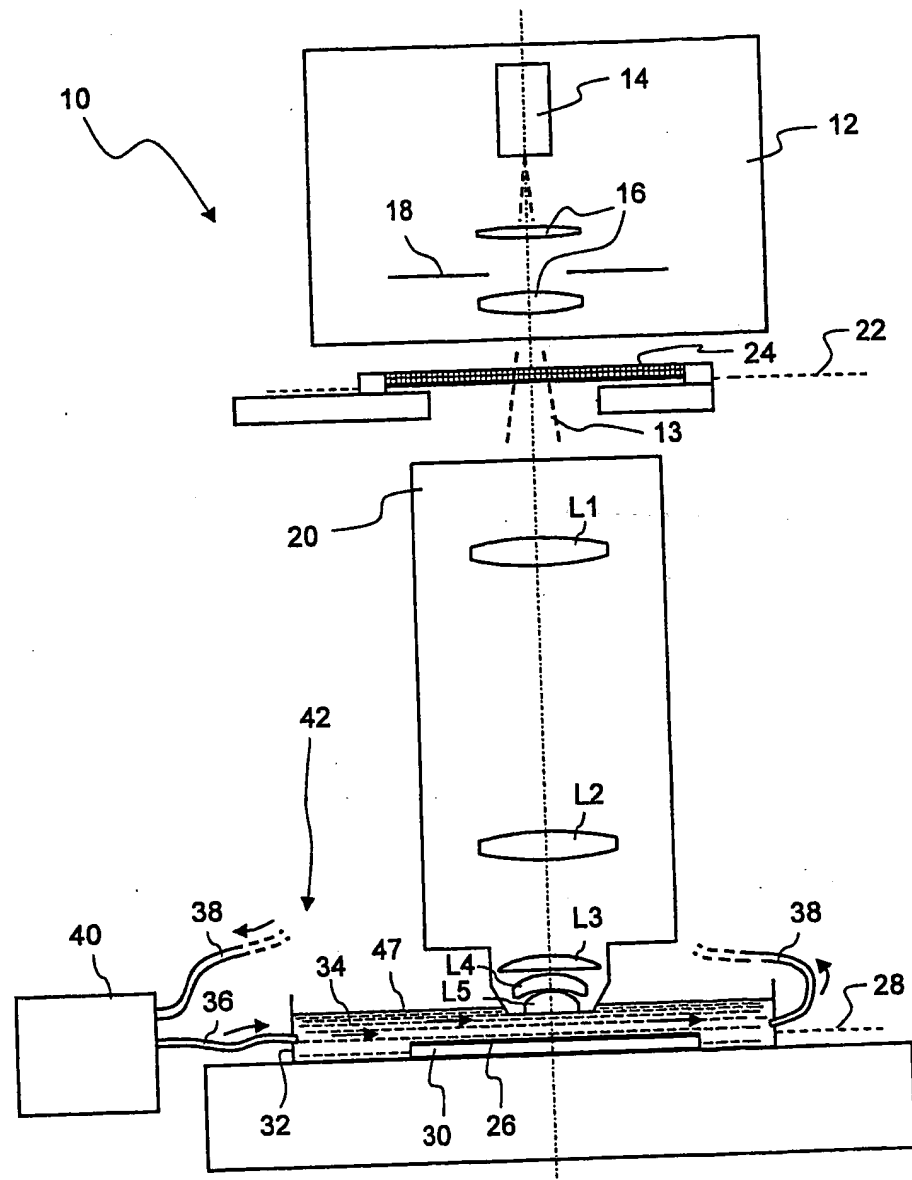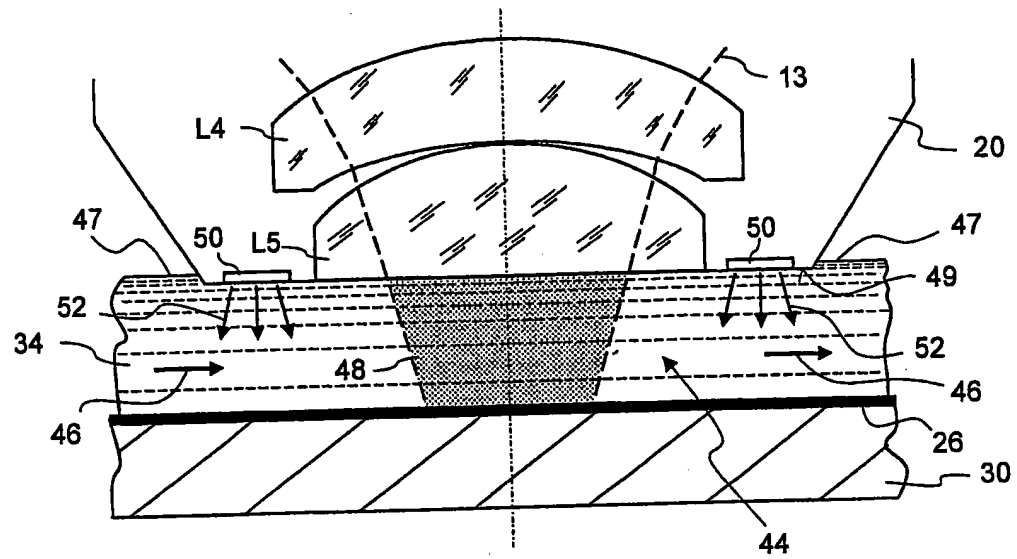
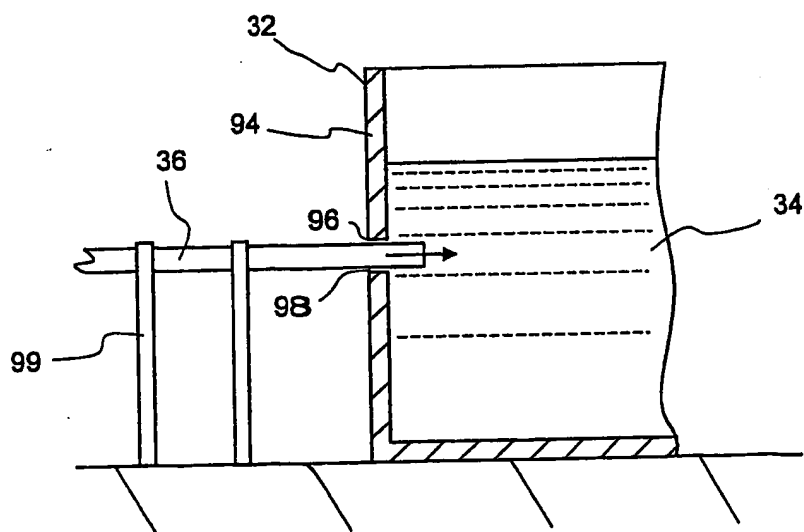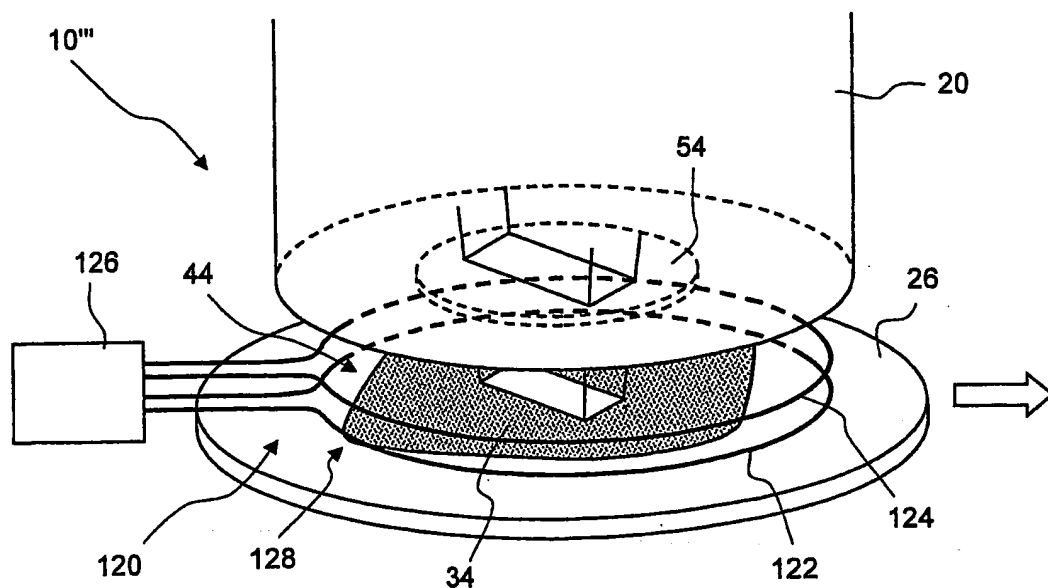Fig. 1

Fig. 2
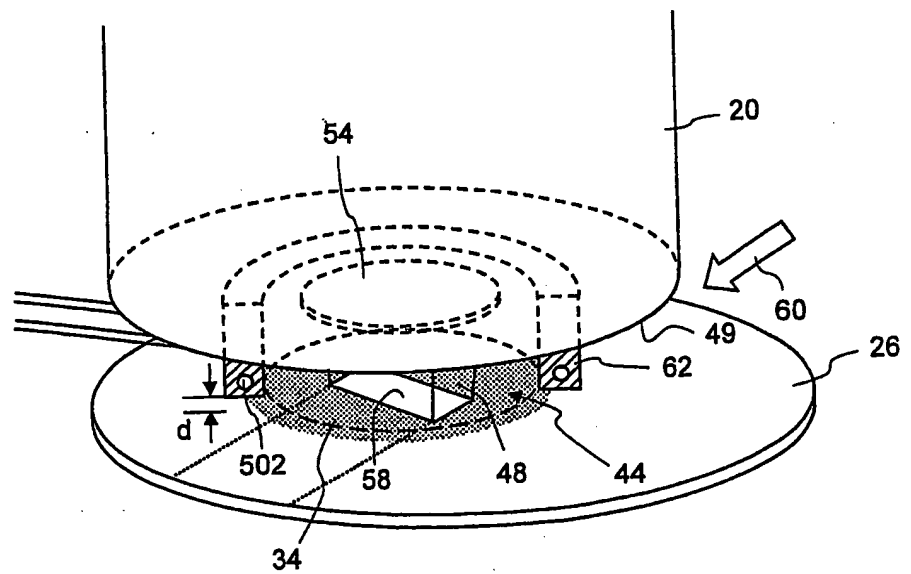
Fig. 5
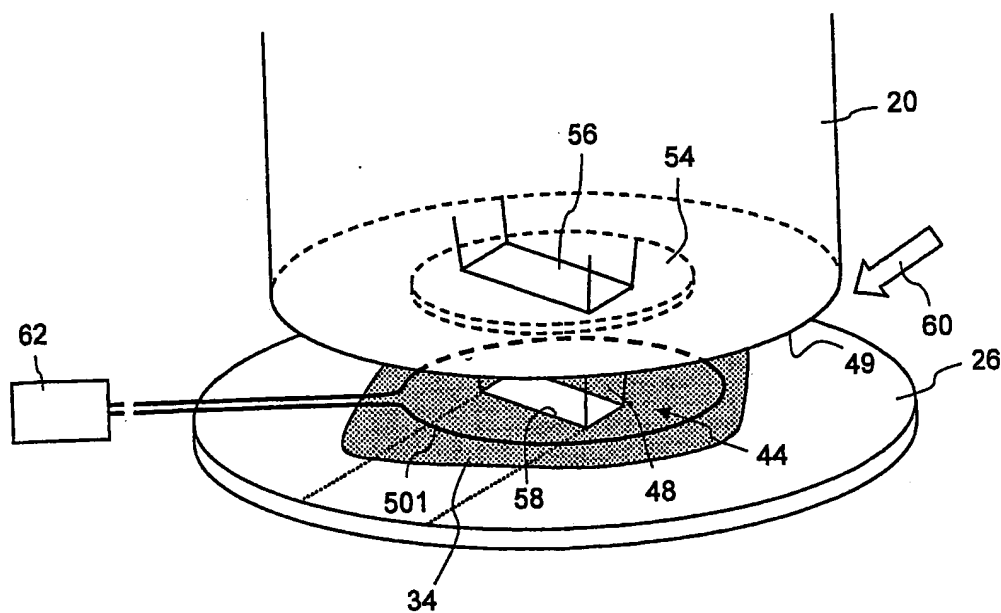
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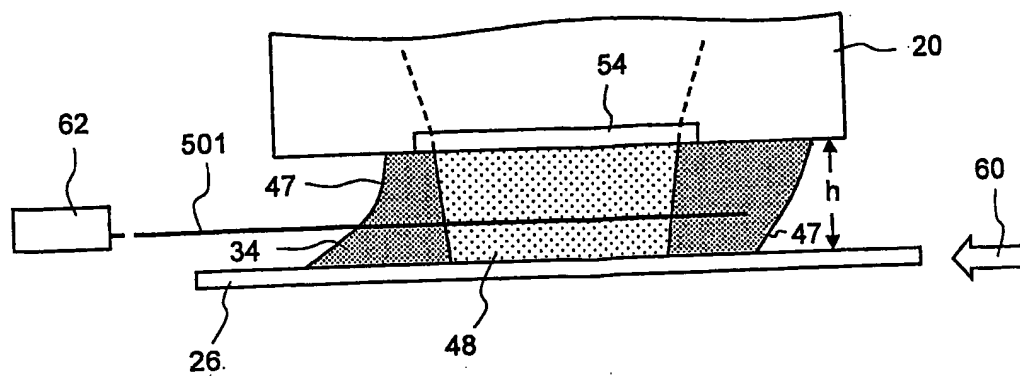
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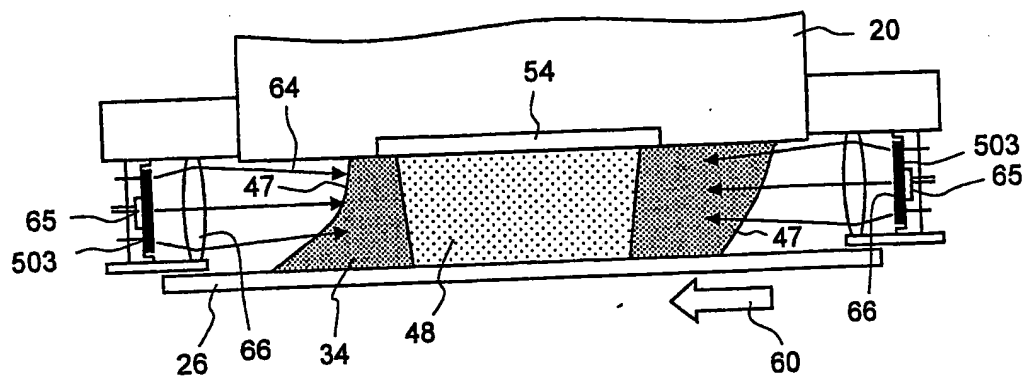
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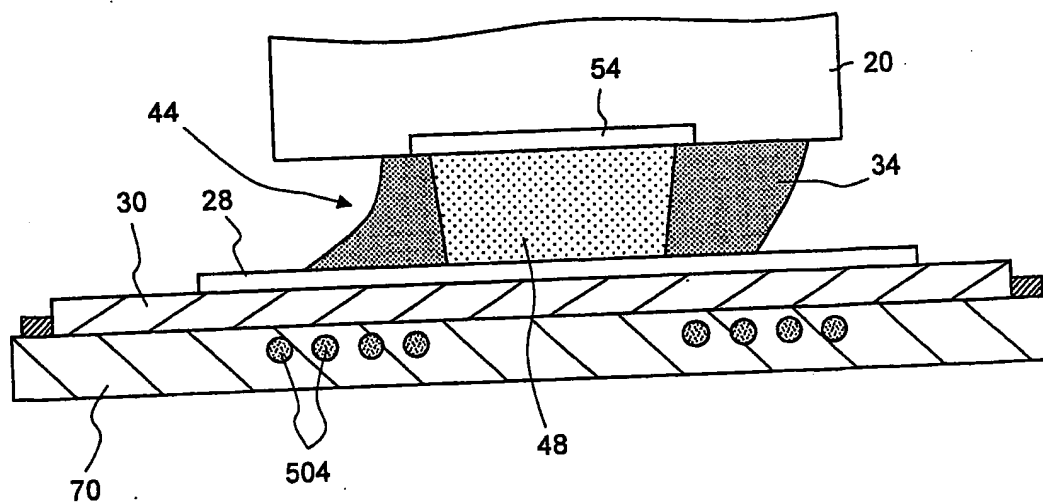
Fig. 7
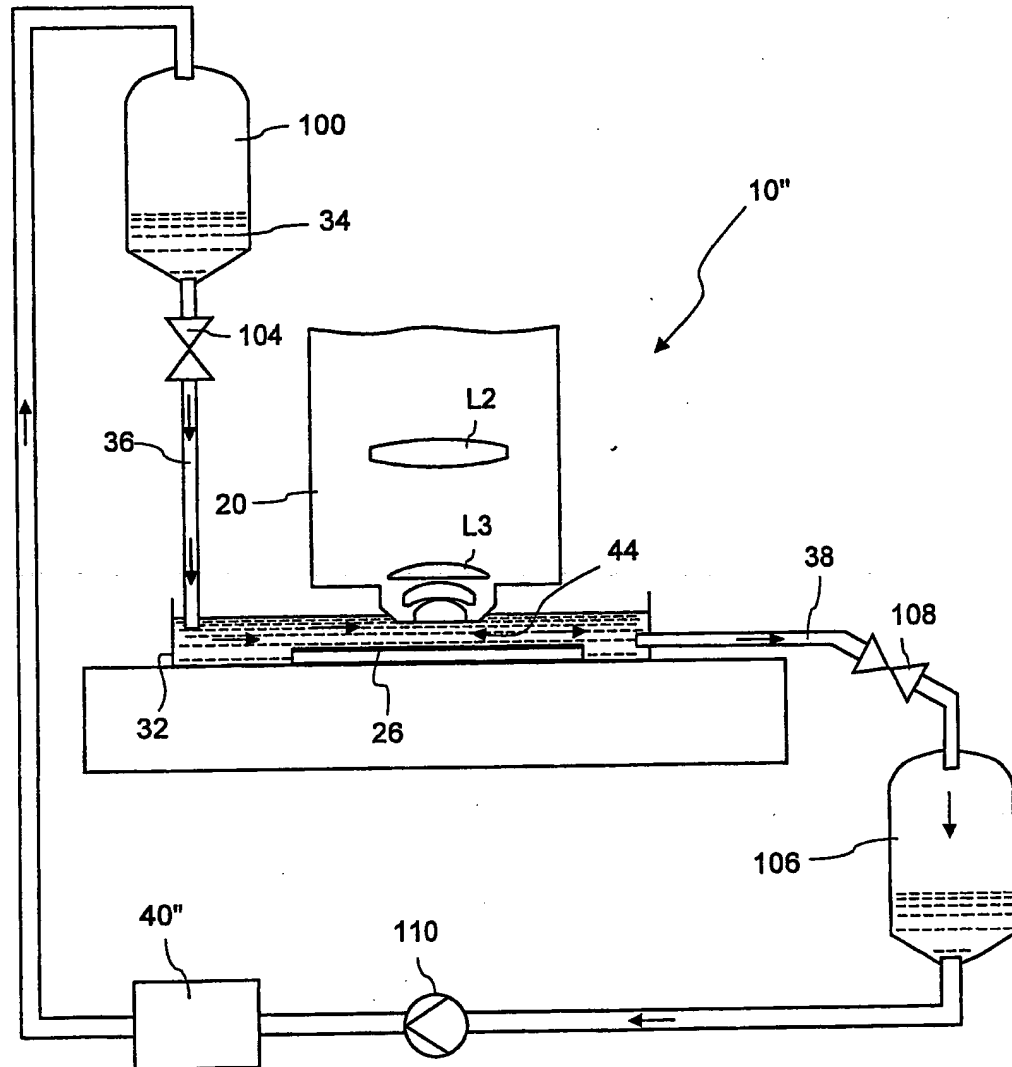
Fig. 11

Fig. 8
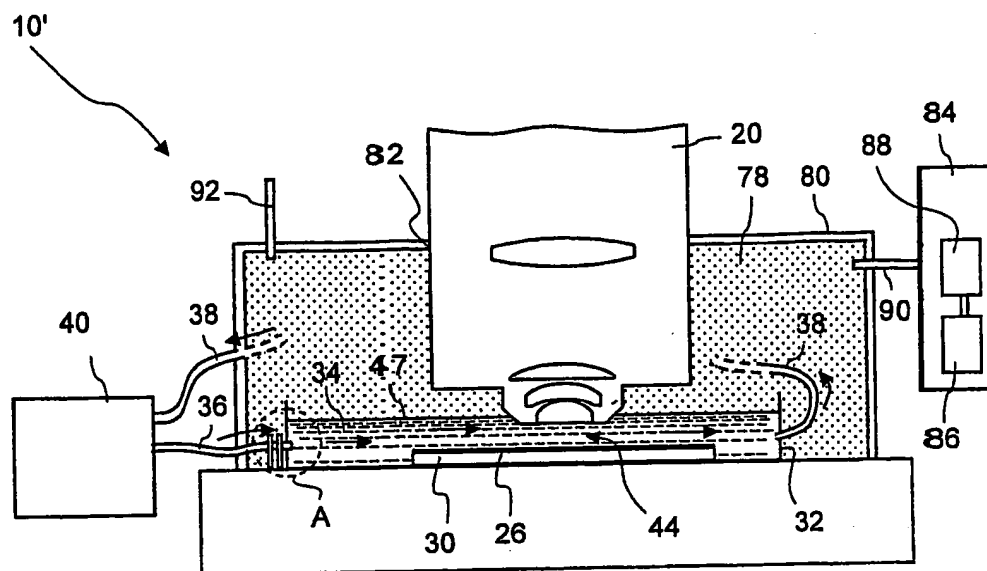
Fig. 9

Fig. 10

Fig. 12

Fig. 13

Fig. 14

Fig. 15